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(54) Method of combustion with low acoustics

(57) A method of reducing pressure fluctuations in the combustor of a gas turbine engine resulting from the combustion of fuel and air therein comprises combust- ing a fuel/air mixture in a combustor downstream of the

exit plane of a fuel nozzle assembly such that such recirculation zones generated by the fuel nozzle assembly are in spaced relation to the exit plane at all operating conditions of the engine.

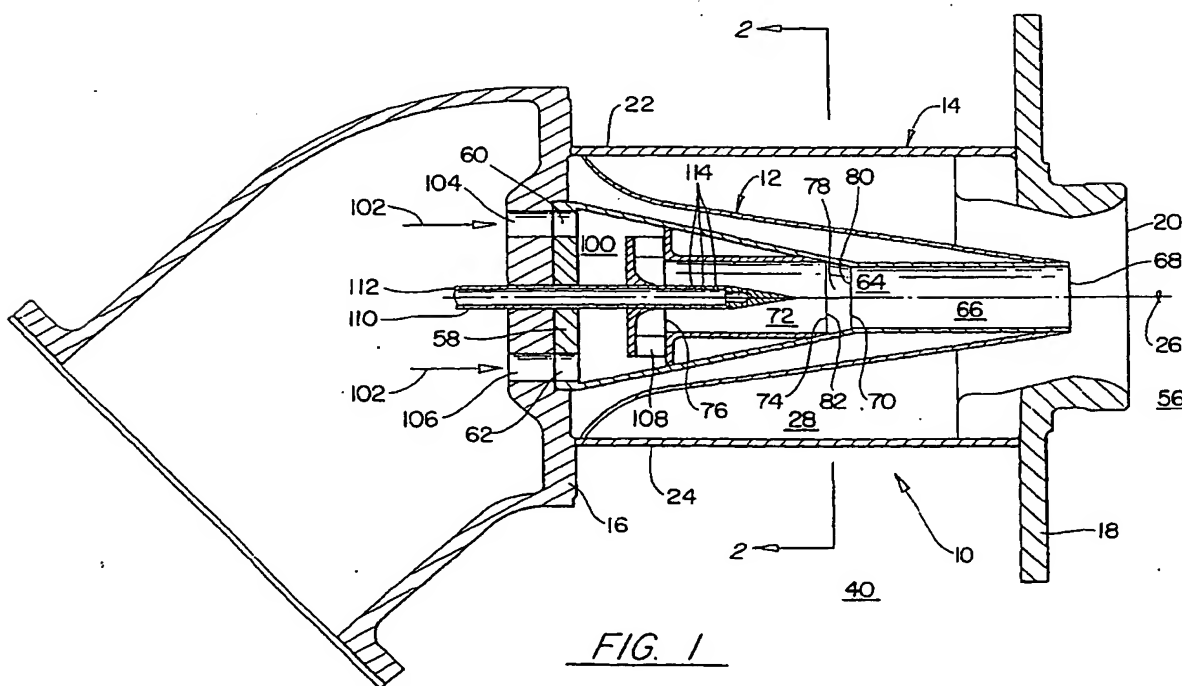


FIG. 1

## Description

This invention relates to low NOx premix fuel nozzles, and particularly to a method of combustion in gas turbine engines.

The production of nitrous oxides (hereinafter "NOx") occurs as a result of combustion at high temperatures. NOx is a notorious pollutant, and as a result, combustion devices which produce NOx are subject to ever more stringent standards for emissions of such pollutants. Accordingly, much effort is being put forth to reduce the formation of NOx in combustion devices.

One solution has been to premix the fuel with an excess of air such that the combustion occurs with local high excess air, resulting in a relatively low combustion temperature and thereby minimizing the formation of NOx. A fuel nozzle which so operates is shown in U.S. Pat. No. 5,307,634, which discloses a scroll swirler with a conical center body. This type of fuel nozzle is known as a tangential entry fuel nozzle, and comprises two offset cylindrical-arc scrolls connected to two endplates. Combustion air enters the swirler through two substantially rectangular slots formed by the offset scrolls, and exits through a combustor inlet port in one endplate and flows into the combustor. A linear array of orifices located on the outer scroll opposite the inner trailing edge injects fuel into the airflow at each inlet slot from a manifold to produce a uniform fuel air mixture before exiting into the combustor.

Premix fuel nozzles of the tangential entry type have demonstrated low emissions of NOx relative to fuel nozzles of the prior art. Unfortunately, fuel nozzles such as the one disclosed in the aforementioned patent have been shown, at certain operating conditions, to produce acoustic tones and excessive combustor pressure fluctuations which lead to deterioration of the gas turbine engine. As a result, tangential entry fuel nozzles of this type have not been incorporated into commercially available gas turbine engines.

What is needed is a method of combustion that significantly reduces the acoustic effects that lead to the excessive combustor pressure fluctuations.

Accordingly, there is disclosed herein a method of reducing pressure fluctuations in the combustor of a gas turbine engine resulting from the combustion of fuel and air which comprises mixing fuel and air in a mixing zone within a fuel nozzle assembly, thereby producing a fuel/air mixture, flowing the mixture into a combustor through an exit plane of a combustor inlet port downstream of the mixing zone, flowing a first portion of the mixture into a central recirculation zone and combusting at least some of the first portion of the mixture therein, flowing a second portion of the mixture into an outer recirculation zone radially outward from the central recirculation zone and combusting at least some of the second portion of the mixture, and maintaining the recirculation zones in spaced relation to the exit plane at all operating conditions of the engine.

Some preferred embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Figure 1 is a cross-sectional view of the a fuel nozzle for operating the present invention, taken along line 1-1 of Figure 2.

Figure 2 is a cross-sectional view looking down the longitudinal axis of the nozzle of Figure 1.

Figure 3 is a cross-sectional view of the fuel nozzle, taken along line 3-3 of Figure 2.

Figure 4 is a cross section through a further nozzle for operating the invention, which differs from the fuel nozzle of Figures 1 to 3 only in the shape of its combustor inlet port.

Referring to Figure 1, the low NOx premix fuel nozzle 10 of the present invention includes a centerbody 12 within a scroll swirler 14. The scroll swirler 14 includes first and second endplates 16, 18, and the first endplate is connected to the centerbody 12 and is in spaced relation to the second endplate 18, which has a combustor inlet port 20 extending therethrough. A plurality, and preferably two, cylindrical-arc scroll members 22, 24 extend from the first endplate 16 to the second endplate 18.

The scroll members 22, 24 are spaced uniformly about the longitudinal axis 26 of the nozzle 10 thereby defining a mixing zone 28 therebetween, as shown in Figure 2. Each scroll member 22, 24 has a radially inner surface which faces the longitudinal axis 26 and defines a surface of partial revolution about a centerline 32, 34. As used herein, the term "surface of partial revolution" means a surface generated by rotating a line less than one complete revolution about one of the centerlines 32, 34.

Each scroll member 22 is in spaced relation to the other scroll member 24, and the centerline 32, 34 of each of the scroll members 22, 24 is located within the mixing zone 28, as shown in Figure 2. Referring to Figure 3, each of the centerlines 32, 34 is parallel, and in spaced relation, to the longitudinal axis 26, and all of the centerlines 32, 34 are located equidistant from the longitudinal axis 26, thereby defining inlet slots 36, 38 extending parallel to the longitudinal axis 26 between each pair of adjacent scroll members 22, 24 for introducing combustion air 40 into the mixing zone 28. Combustion supporting air 42 from the compressor (not shown) passes through the inlet slots 36, 38 formed by the overlapping ends 44, 50, 48, 46 of the scroll members 22, 24 with offset centerlines 32, 34.

Each of the scroll members 22, 24 further includes a fuel conduit 52, 54 for introducing fuel into the combustion air 40 as it is introduced into the mixing zone 28 through one of the inlet slots 36, 38. A first fuel supply line (not shown), which may supply either a liquid or gas fuel, but preferably gas, is connected to each of the fuel conduits 52, 54. The combustor inlet port 20, which is coaxial with the longitudinal axis 26, is located immediately adjacent the combustor 56 to discharge the fuel

and combustion air from the present invention into the combustor 56, where combustion of the fuel and air takes place.

Referring back to Figure 1, the centerbody 12 has a base 58 that has at least one, and preferably a plurality, of air supply ports 60, 62 extending therethrough, and the base 58 is perpendicular to the longitudinal axis 26 extending therethrough. The centerbody 12 also has an internal passageway 64 that is coaxial with the longitudinal axis 26 and discharges into the combustor inlet port 20. The air passing through the internal passageway 64, which is preferably co-rotating with the combustion air entering through the inlet slots 36, 38 but may be counter-rotating or non-rotating, may or may not be fuelled. If fuelling of the centerbody is desired, in the preferred embodiment of the invention, the internal passageway 64 includes a first cylindrical passage 66 having a first end 68 and a second end 70, and a second cylindrical passage 72 of greater diameter than the first cylindrical passage 66 and likewise having a first end 74 and a second end 76. The second cylindrical passage 72 communicates with the first cylindrical passage 66 through a tapered passage 78 having a first end 80 that has a diameter equal to the diameter of the first cylindrical passage 66, and a second end 82 that has a diameter equal to the diameter of the second cylindrical passage 72. Each of the passages 66, 72, 78 is coaxial with the longitudinal axis 26, and the first end 80 of the tapered passage 78 is integral with the second end 70 of the first cylindrical passage 66, while the second end 82 of the tapered passage 78 is integral with the first end 74 of the second cylindrical passage 72. The first cylindrical passage 66 includes a discharge orifice 68 that is circular and coaxial with the longitudinal axis 26, and is located at the first end 68 of the first cylindrical passage 66.

Referring to Figure 3, the radially outer surface 84 of the centerbody 12 includes a frustum portion 86, which defines the outer surface of a frustum that is coaxial with the longitudinal axis 26 and flares toward the base 58, and a curved portion 88 which is integral with the frustum portion 86 and preferably defines a portion of the surface generated by rotating a circle, which is tangent to the frustum portion 86 and has a center which lies radially outward thereof, about the longitudinal axis 26. In the preferred embodiment, the frustum portion 86 terminates at the plane within which the discharge orifice 68 is located, the diameter of the base (not to be confused with the base 58 of the centerbody) of the frustum portion 86 is 2.65 times greater than the diameter of the frustum portion 86 at the apex thereof, and the height 90 of the frustum portion 86 (the distance between the plane in which the base of the frustum portion 86 is located and the plane in which the apex of the frustum portion 86 is located) is approximately 1.90 times the diameter of the frustum portion 86 at the base thereof. As described in further detail below, the curved portion 88, which is located between the base 58 and the

frustum portion 86, provides a smooth transitional surface that axially turns combustion air 40 entering the tangential entry nozzle 10 adjacent the base 58. As shown in Figure 3, the internal passageway 64 is located radially inward from the radially outer surface 84 of the centerbody 12, the frustum portion 86 is coaxial with the longitudinal axis 26, and the centerbody 12 is connected to the base 58 such that the frustum portion 86 tapers toward, and terminates at the discharge orifice 68 of the first cylindrical passage 66.

As shown in Figure 2, the base of the frustum portion 86 fits within a circle 92 inscribed in the mixing zone 28 and having its center 94 on the longitudinal axis 26. As those skilled in the art will readily appreciate, since the mixing zone 28 is not circular in cross section, the curved portion 88 must be cut to fit therein. A ramp portion 96, 98 is left on the curved portion 88 where the curved portion 88 extends into each inlet slot 36, 38, and this portion is machined to form an aerodynamically shaped ramp 96, 98 that directs the air entering the inlet slot 36, 38 away from the base 58 and onto the curved portion 88 within the mixing zone 28.

Referring to Figure 1, in the preferred embodiment, an internal chamber 100 is located within the centerbody 12 between the base 58 and the second end 76 of the second cylindrical passage 72, which terminates at the chamber 100. Air 102 is supplied to the chamber 100 through the air supply ports 60, 62 in the base 58 which communicate therewith, and the chamber 100, in turn, supplies air to the internal passageway 64 through the second end 76 of the second cylindrical passage 72. The first endplate 16 has openings 104, 106 therein that are aligned with the air supply ports 60, 62 of the base 58 so as not to interfere with the flow of combustion air 102 from the compressor of the gas turbine engine. A swirler 108, preferably of the radial inflow type known in the art, is coaxial with the longitudinal axis 26 and is located within the chamber 100 immediately adjacent the second end 76 of the second cylindrical passage 72 such that all air entering the internal passageway 64 from the chamber 100 must pass through the swirler 108.

Preferably a fuel lance 110, which likewise is coaxial with the longitudinal axis 26, extends through the base 58, the chamber 100, and the swirler 108, and into the second cylindrical passage 72 of the internal passageway 64. The larger diameter of the second cylindrical passage 72 accommodates the cross-sectional area of the fuel lance 110, so that the flow area within the second cylindrical passage 72 is essentially equal to the flow area of the first cylindrical passage 66. A second fuel supply line (not shown), which may supply either a liquid or gas fuel, is connected to the fuel lance 110 to supply fuel to an inner passage 112 within the fuel lance 110. Fuel jets 114 are located in the fuel lance 110, and provide a pathway for fuel to exit from the fuel lance 110 into the internal passageway 64.

Referring to Figure 3, the combustor inlet port 20 is

coaxial with the longitudinal axis 26 and includes a convergent surface 116 and a discharge surface 118 which extends to the exit plane 124 of the fuel nozzle 10 and can be divergent as shown in Figure 3, convergent, or cylindrical as shown in Figure 4. Referring to Figure 4 (which differs only from Figure 3 in the shape of the combustor inlet port 20, all other details being the same and thus bearing the same reference numerals) the convergent surface 116 and the cylindrical surface 118' are likewise coaxial with the longitudinal axis 26, and the convergent surface 116 is located between the first endplate 16 and the cylindrical surface 118'. The convergent surface 116 is substantially conical in shape and tapers toward the cylindrical surface 118'. The cylindrical surface 118' extends between the throat plane 120 of the port 20 and the combustor surface 122 of the combustor port inlet 20, which is perpendicular to the longitudinal axis 26, and defines the exit plane 124 of the fuel nozzle 10.

The convergent surface 116 terminates at the throat plane 120, where the diameter of the convergent surface 116 is equal to the diameter of the cylindrical surface 118'. As shown in Figure 3, the throat plane 120 is located between the exit plane 124 and the discharge orifice 68 of the internal passageway 64, and the convergent surface 116 is located between the cylindrical surface 118' and the first endplate 16. In order to establish the desired velocity profile of the fuel/air mixture within the combustor inlet port 20, the convergent surface 116 extends a predetermined distance 126 along the longitudinal axis 26 and the cylindrical surface 118' extends a second distance 128 along the longitudinal axis 26 that is preferably at least 30% of the predetermined distance 126. Also, the combustion air flowing therethrough should in preferred embodiments encounter the minimum flow area, or throat area, at the combustor inlet port 20. To achieve this result, the cylindrical surface 118' is preferably located at a predetermined radius from the longitudinal axis 26 that is at least 10% less than the radius of the base of the frustum portion 86.

In operation, combustion air from the compressor of the gas turbine engine flows through the openings 104, 106 and the air supply ports 60, 62 in the base 58 and into the chamber 100 of the centerbody 12. The combustion air exits the chamber 100 through the radial inflow swirler 108 and enters the internal passageway 64 with a substantial tangential velocity, or swirl, relative to the longitudinal axis 26. When this swirling combustion air passes the fuel lance 110, fuel, preferably in gaseous form, is sprayed from the fuel lance 110 into the internal passage 64 and mixes with the swirling combustion air. The mixture of fuel and combustion air then flows from the second cylindrical passage 72 into the first cylindrical passage 66 through the tapered passage 78. The mixture then proceeds down the length of the first cylindrical passage 66, exiting the first cylindrical passage 66 just short of, or at, the throat plane 120 of the combustor inlet port 20, providing a central stream

of fuel air mixture.

Additional combustion air from the compressor of the gas turbine engine enters the mixing zone 28 through each of the inlet slots 36, 38. Air entering the inlet slots 36, 38 immediately adjacent the base 58 is directed by the ramps 96, 98 onto the curved portion 88 within the mixing zone 28 of the scroll swirler 14. Fuel, preferably gaseous fuel, supplied to the fuel conduits 52, 54 is sprayed into the combustion air passing through the inlet slots 36, 38 and begins mixing therewith. Due to the shape of the scroll members 22, 24, this mixture establishes an annular stream swirling about the centerbody 12, and the fuel/air mixture continues to mix as it swirls thereabout while progressing along the longitudinal axis 26 toward the combustor inlet port 20.

The swirl of the annular stream produced by the scroll swirler 14 is preferably co-rotational with the swirl of the fuel/air mixture in the first cylindrical passage 66, and preferably has an angular velocity at least as great as the angular velocity of the fuel/air mixture in the first cylindrical passage 66. Due to the shape of the centerbody 12, the axial velocity of the annular stream is maintained at speeds which prevent the combustor flame from migrating into the scroll swirler 14 and attaching to the outer surface 84 of the centerbody 12. Upon exiting the first cylindrical passage 66, the swirling fuel/air mixture of the central stream is surrounded by the annular stream of the scroll swirler 14, and the two streams enter the throat 120 of the combustor inlet port 20 and flow radially inward of the divergent surface 118 or the cylindrical surface 118' until reaching the exit plane 124 of the combustion inlet port 20 downstream of the mixing zone 28.

Upon exiting the combustor inlet port 20, the interaction of the central stream with the annular stream creates a central recirculation zone 200 which is downstream from the exit plane 124 (i.e. the exit plane lies between the central recirculation zone and the discharge orifice of the internal passageway) and in spaced relation thereto. The sharp lip 130 formed where the divergent surface 118 or cylindrical surface 118' meets the combustor surface 122 of the combustor inlet port 20 causes sudden expansion of the fuel/air mixture and recirculation of the fuel/air mixture radially outward of the central recirculation zone 200. The combustion and flame produced in this outer recirculation 300 anchors this "outer" flame adjacent the lip 130, but the flame is in spaced relation to the exit plane 124 and entirely downstream thereof. As a result of the design of the present invention, both recirculation zones 200, 300 are maintained in spaced relation to the exit plane 124 at all engine operating conditions.

The fuel nozzle 10 described substantially reduces the flow oscillations and attendant heat release rates resulting therefrom, which caused excessive combustor pressure fluctuations and an acoustic tone. The method of combustion described eliminates the aforementioned interaction between the combustion process and the ex-

it plane 124, resulting in significantly lower acoustic fluctuations. Consequently, the present invention provides a solution to the problem of excessive pressure fluctuations in the tangential entry fuel nozzle 10 while achieving the low emissions performance thereof.

Although this invention has been shown and described with respect to a detailed embodiment thereof, it will be understood by those skilled in the art that various changes in form and detail thereof may be made without departing from the scope of the claimed invention. For example, the centerbody of the described nozzle may have its curved outer wall 84 omitted, leaving an outer wall having a frustum and a cylindrical portion..

### Claims

1. A method of reducing pressure fluctuations in the combustor of a gas turbine resulting from the combustion of fuel and air therein, said method comprising:

mixing fuel and air in a mixing zone (28) within a fuel nozzle assembly (10), thereby producing a fuel/air mixture;  
flowing the mixture into a combustor through an exit plane of a combustor inlet port (20) downstream of said mixing zone;  
flowing a first portion of the mixture into a central recirculation zone (200) and combusting at least some of said first portion of said mixture therein;  
flowing a second portion of the mixture into an outer recirculation zone (300) radially outward from said central recirculation zone and combusting at least some of said second portion of said mixture;  
maintaining said recirculation zones (200, 300) in spaced relation to said exit plane at all operating conditions of said engine.

2. A method of reducing pressure fluctuations in the combustor of a gas turbine resulting from the combustion of fuel and air therein, said method comprising:

providing a fuel nozzle assembly (10) including a centerbody (12) having a longitudinal axis, a radially outer surface (84) including a frustum portion (86) defining the outer surface of a frustum that is coaxial with the longitudinal axis and flares toward the frustum base thereof, and a curved portion (88) which is integral with the frustum portion, a centerbody base (58), said centerbody base having at least one air supply port extending therethrough, an internal passageway (64) coaxial with the longitudinal axis; mixing fuel and air within the nozzle (10), there-

by producing a fuel/air mixture;  
flowing the mixture into the combustor through the exit plane (124) of the combustor inlet port (20);

flowing a first portion of the mixture into a central recirculation zone (200) and combusting at least some of said first portion of said mixture therein;

flowing a second portion of the mixture into an outer recirculation zone (300) radially outward from said central recirculation zone and combusting at least some of said second portion of said mixture; and

maintaining said recirculation zones in spaced relation to said exit plane at all operating conditions of said engine.

3. A method as claimed in claim 2 wherein said curved portion (88) defines a portion of the surface generated by rotating a circle which is tangent to the frustum portion and has a center which lies radially outward thereof about the longitudinal axis.

4. A fuel nozzle assembly comprising:

a centerbody (12) having a longitudinal axis (26), a radially outer surface (84) including a frustum portion (86), a centerbody base (58) with at least one air supply port extending therethrough, and an internal passageway (64) coaxial with the longitudinal axis for producing a central flow stream;  
a scroll swirler (14) having for producing an annular flow stream around said centerbody 12 and comprising an endplate (18) with a combustor inlet port (20) extending therethrough, said inlet port coaxial with said axis and including a convergent surface (116), a combustor surface (122), and a surface (118; 118') extending from said convergent surface to said combustor surface.

5. A fuel nozzle as claimed in claim 4 wherein the surface (118) extending between the convergent surface (116) and the combustor surface (122) is divergent.

6. A fuel nozzle as claimed in claim 4 wherein the surface (118') extending between the convergent surface (116) and the combustor surface (122) is cylindrical.

7. A fuel nozzle as claimed in claim 4, 5 or 6 wherein the surface (118; 118') extending between the convergent surface (116) and the combustor surface (122) meets the combustion surface at a sharp lip (130).

8. A fuel nozzle as claimed in any of claims 4 to 7 wherein said internal passageway of said center-body extends to said inlet port (20).

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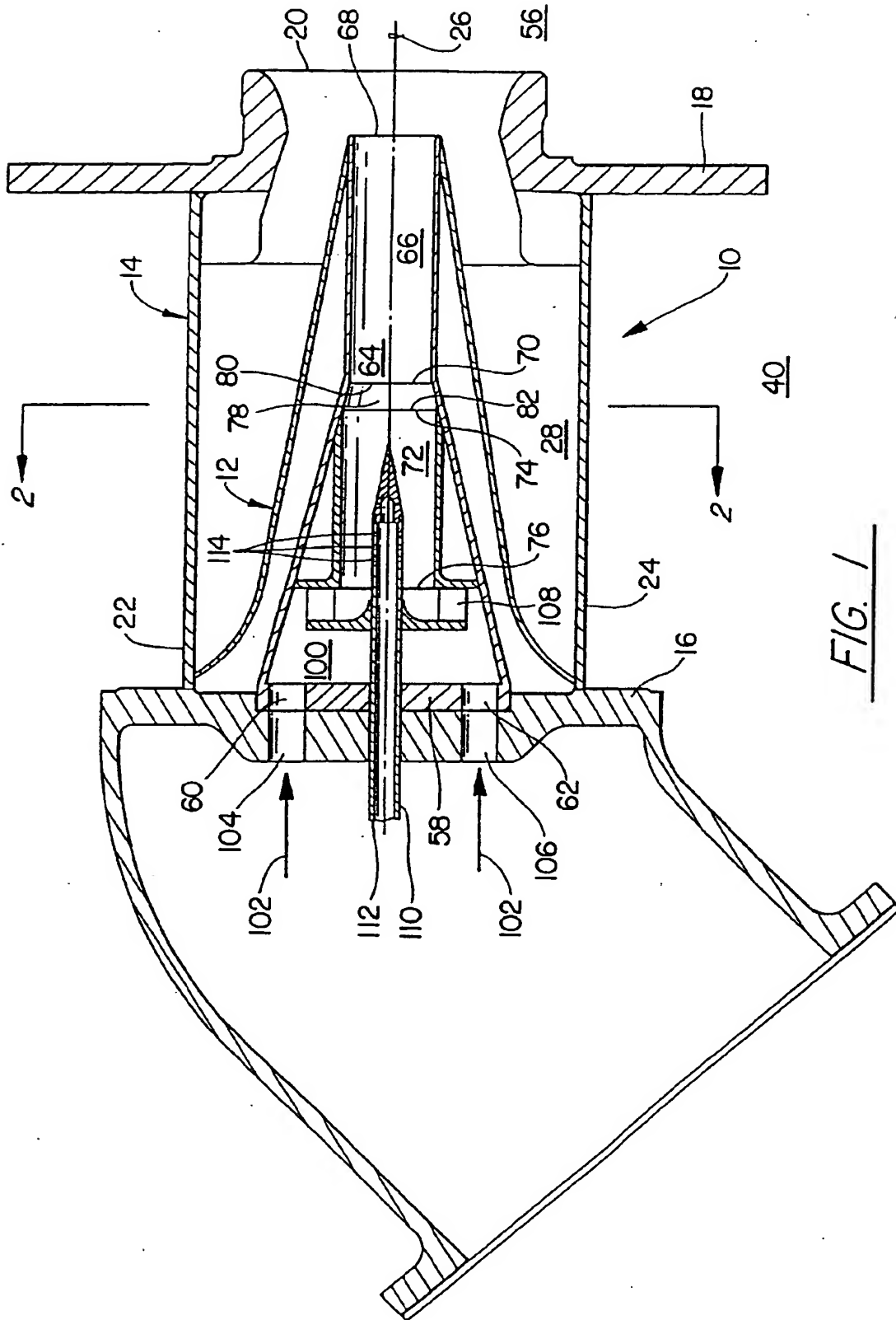
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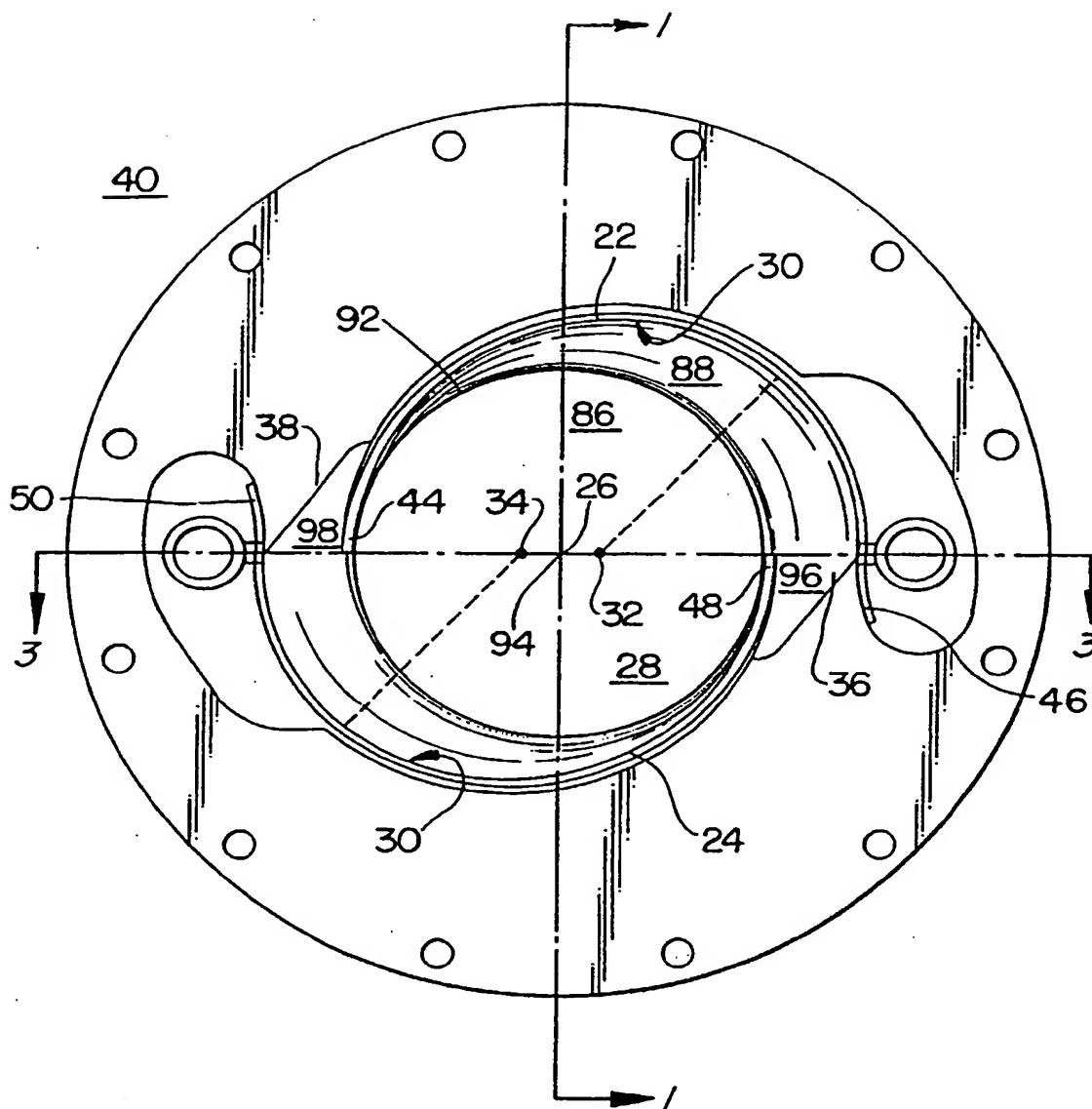


FIG. 2



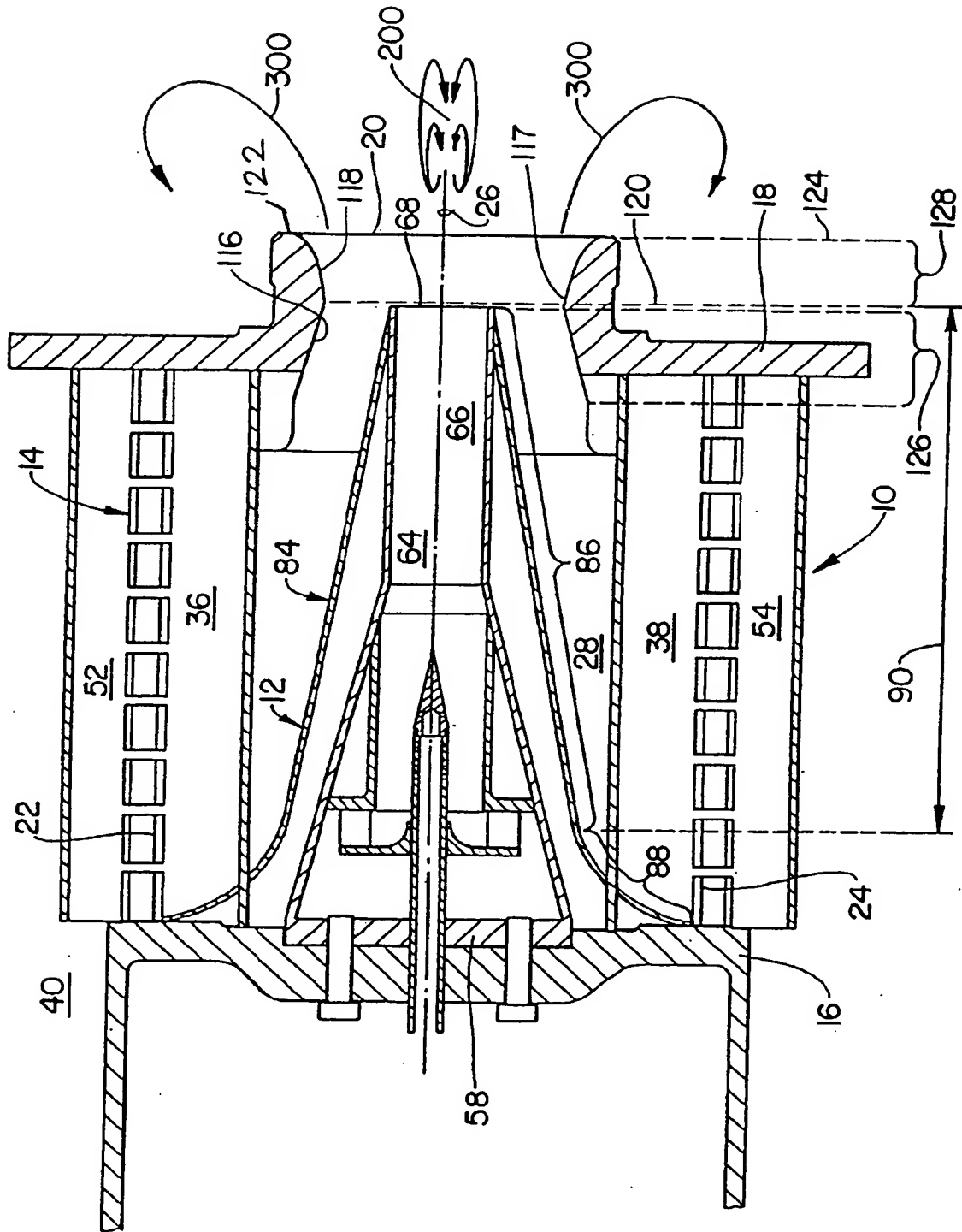


FIG. 3

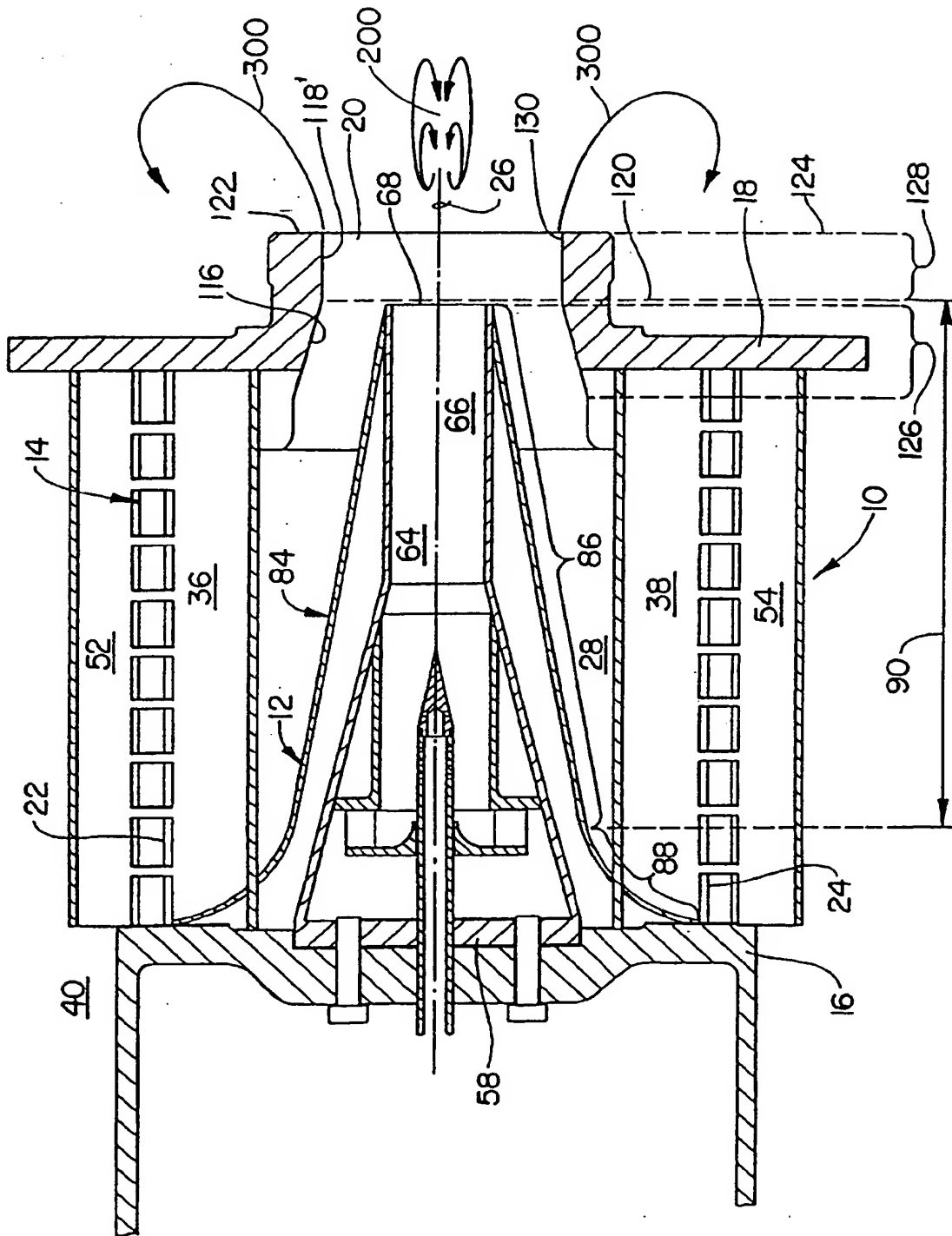


FIG. 4



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(30) Priority: 20.12.1996 US 770276

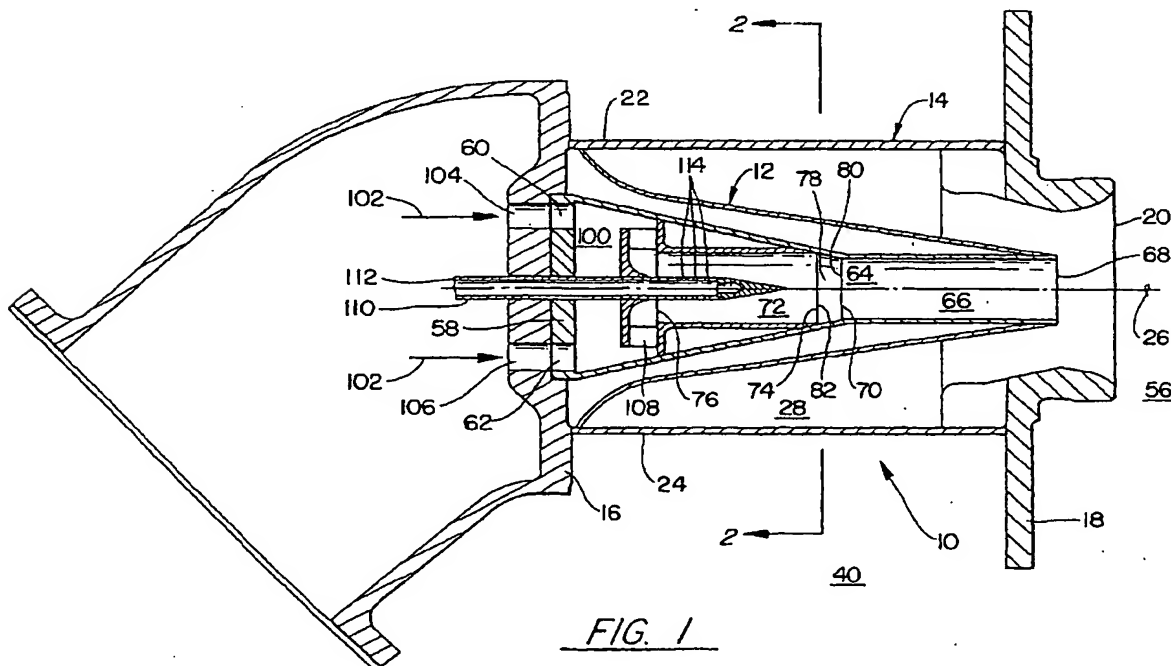
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# EUROPEAN SEARCH REPORT

Application Number  
EP 97 31 0465

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Incl. 6)
X A	US 5 471 840 A (LOVETT JEFFERY A) 5 December 1995 (1995-12-05)  * column 1, line 11 - line 61 * * column 2, line 61 - column 3, line 24 * * figure 1 * ---	1  2	F23C7/00 F23C9/00
X A	US 5 251 447 A (JOSHI NARENDRA D ET AL) 12 October 1993 (1993-10-12)  * column 1, line 48 - line 50 * * column 3, line 67 - column 7, line 2 * * figures 1,2 * ---	1  2	
A	US 2 515 845 A (VAN DEN BUSSCHE HENDRIK K.J.) 18 July 1950 (1950-07-18) * column 1, line 23 - column 2, line 9 * * column 3, line 63 - column 4, line 6 * * figure 3 * -----	1	
			TECHNICAL FIELDS SEARCHED (Incl. 6)
			F23C F23D F23R
-The present search report has been drawn up for all claims			
Place of search <b>THE HAGUE</b>		Date of completion of the search <b>29 April 1999</b>	Examiner <b>Coquau, S</b>
CATEGORY OF CITED DOCUMENTS X: particularly relevant if taken alone Y: particularly relevant if combined with another document of the same category A: technological background O: non-written disclosure P: intermediate document T: theory or principle underlying the invention E: earlier patent document, but published on, or after the filing date D: document cited in the application L: document cited for other reasons Z: member of the same patent family, corresponding document			

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Office

Application Number  
EP 97 31 0465

**CLAIMS INCURRING FEES**

The present European patent application comprised at the time of filing more than ten claims.

- ☐ Only part of the claims have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims and for those claims for which claims fees have been paid, namely claim(s):
- ☐ No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims.

**LACK OF UNITY OF INVENTION**

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

see sheet B

- ☐ All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.
- ☐ As all searchable claims could be searched without effort justifying an additional fee, the Search Division did not invite payment of any additional fee.
- ☐ Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid, namely claims:
- ☒ None of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims, namely claims:

1-3



European Patent  
Office

LACK OF UNITY OF INVENTION  
SHEET B

Application Number  
EP 97 31 0465

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

1. Claims: 1-3

Method of reducing pressure fluctuations in the combustor of a gas turbine consisting on:

- mixing fuel and air in a mixing zone,
- and flowing a first portion of the mixture in a central recirculation zone and a second portion of the mixture in an outer recirculation zone.

2. Claims: 4-8

A fuel nozzle assembly comprising a centerbody and a scroll swirler to produce an annular flow stream around the centerbody.

ANNEX TO THE EUROPEAN SEARCH REPORT  
ON EUROPEAN PATENT APPLICATION NO.

EP 97 31 0465

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.  
The members are as contained in the European Patent Office EDP file on  
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29-04-1999

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5471840 A	05-12-1995	NONE	
US 5251447 A	12-10-1993	NONE	
US 2515845 A	18-07-1950	NONE	

EPO FORM P0158

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82